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Use of Lunar Orbiter Photographs In Earth Science Courses

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INTRODUCTION

In recent years, the national Aeronautics and Space Administration has generated a large volume of material of interest to earth scientists. Much of it is eminently suitable for use in elementary earth science and geology courses, or in more advanced courses such as stratigraphy. This material is generally not difficult to obtain, but it is almost impossible for someone not actively using it to know which of the many thousands of photographs are best for geologic studies.

This paper suggests a very small number of Lunar Orbiter photographs that we believe are superior for illustrating geologic features and the principles of stratigraphy and historical geology. Only Orbiter photographs are considered. Some of the Apollo pictures currently becoming available are certainly spectacular, but few are as suitable as the Orbiter photographs for general geologic purposes. Reference to available Apollo photographs is included in the appendix, which also includes information on ordering Orbiter photographs, lunar maps, and other useful materials.

Three books and one general geologic map are particularly useful, and should be available to students for reference. These are: Mutch (1970), Kosofsky and El-Baz (1970), Lowman (1969), and Wilhelms and McCauley (in press).

Mutch's book is an excellent survey of lunar geology which strongly emphasizes stratigraphy and historical geology, and which has a good bibliography. The Kosofsky and El-Baz book contains many Orbiter pictures organized to show the classical features of the lunar surface, as well as a lucid section on the technology of the Orbiter missions. Its only drawback is the poor reproduction of many of the pictures. The Lowman book is similar, but with more emphasis on geologic features and much better reproduction of photographs. It has a particulary good section on crater characteristics. Finally, the geologic map provides an excellent overview of lunar geology.

The usefulness of Orbiter photographs is greatly enhanced if their locations are known. Consequently, indexes for each Orbiter mission plus some sort of lunar chart are desirable (see appendix). Other basic information such as scale, location of north etc. must be determined for each photograph by the user. Even though lengthy data sheets are provided with each photograph, some small but important details are omitted and some definitions could be clearer. Consequently, the most important parameters and conventions are defined and discussed in the following paragraphs.

PHOTOGRAMMETRY

The pictures from each Lunar Orbiter mission are cataloged by frame numbers, each frame number including a low-resolution (or medium-resolution or moderate-resolution; the terms seem to be used interchangeably), and three high-resolution photographs. The high-resolution photographs cover a small area in the center of the larger area included in the low-resolution photograph. Actually, the high-resolution photographs are one long, narrow photograph cut into three pieces for convenience. Thus photograph IV-109M is a Lunar Orbiter Mission Four low-resolution photograph, and photographs IV-109H_1, IV-109H_2, and IV-109H_3 are the three high-resolution photographs centered within the area of IV-109M. "High resolution" is strictly a relative term, and is based on a comparison with other pictures taken on the same mission. Orbiter V medium-resolution pictures provide a higher resolution than Orbiter IV high-resolution pictures.

Every photograph is divided into many long, narrow, numbered framelets which are 18.2mm wide on

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the standard 20"x24" print. These framelets are artifacts of the system used to transmit the photographic images from the spacecraft to earth. On Orbiter V photographs, the framelet boundaries are oriented approximately north-south whereas on most Orbiter I, II, III, and IV photographs they are oriented approximately east-west. On pictures taken of the visible face of the moon, illumination is from the east. For a more complete discussion of the photographic system, see Kosofsky and El-Baz (1970) or Beeler and Michlovitz (1969).

Locations are given in terms of a lunar latitude and longitude system exactly analagous to the one used on earth; that is, the equator divides the moon into northern and southern hemispheres, and an arbitrary prime meridian passing through the center of the visible face of the moon divides it into eastern and western hemispheres. East is defined, as on earth, as being to the right of an observer standing on the moon facing north. On the data sheets, positive values of latitude are north; positive values of longitude are east. South and west values are thus recorded as negative. Latitude and longitude coördinates of the corners, and lengths of the sides in kilometers are given for each photograph. Figure 1 illustrates this, using frame IV-109 high-resolution as an example. It is important to orient the photographs as shown so that the corners are properly matched to the data-sheet print-out. Note also that dimensions and coördinates given are for all three high-resolution photographs reassembled into one long, narrow photograph.

Of the thirty-four photogrammetric parameters defined on the data sheets, six are of major importance for our purposes. These are:

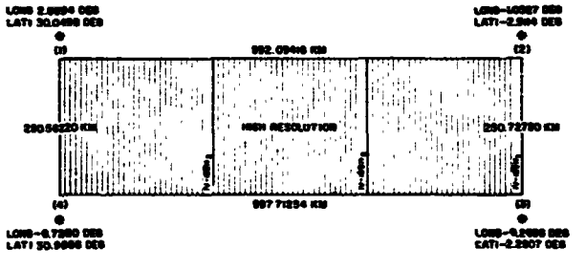

Figure 1: Orientation of photographs for determination of corner co-ordinates. Low-resolution photographs also oriented with legend to right. This orientation places north approximately to the left on L.O. IV photographs, north approximately up on L.O. V photographs. The array of numbers is copied from the data sheet for frame 109; the outlines of the pictures have been added by the writers for clarity. Numbers (1 to 3 from right to left) for the three parts of the photograph follow the NASA-LRC system.

1) SCALE FACTOR: The number of meters *on the film in the spacecraft* equal to one kilometer on the lunar surface. Two listings are included on the data sheets, one for high-resolution, and the other for low-resolution photographs. For the standard 20"x24" prints, these must be multiplied by the enlargment factor of 7.18. For example, the scale on a 20"x24" print for frame IV-109, high-resolution, would be:

SCALE = 7.18 x SCALE FACTOR (HIGH)
= (7.18) (0.0002265M/Km)
= 0.001627M/Km = 1.627mm/Km
or, 1mm = 0.615Km = 615M

2) NORTH DEVIATION ANGLE: the angle, measured *clockwise* from the *normal* to framelet boundaries, to north (see Figure 2 for proper orientation of photograph and measurement of angle).

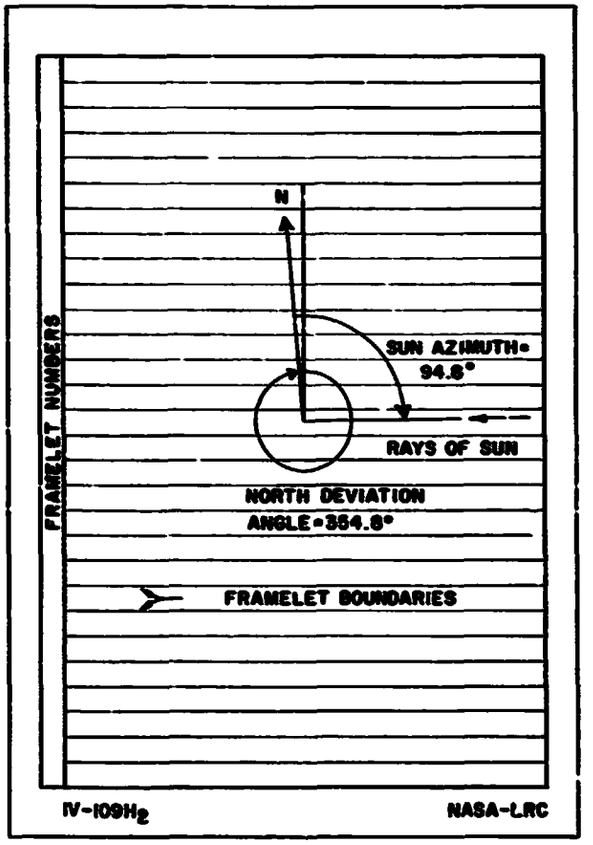

Figure 2: Determination of north and sun azimuth on Orbiter photographs.

3) SUN AZIMUTH at PRINCIPAL GND. PT.: the angle measured *clockwise* from north to the direction from which the sun's rays are coming (see Figure 2).

4) EMISSION ANGLE: the angle between camera axis and the normal to the moon's (idealized) surface at the point where the camera axis intersects the ground (see Figure 3). The *EMISSION ANGLE* provides a measure of obliqueness of the photograph (a 0° *EMISSION ANGLE* means a vertical photograph). On photographs with an *EMISSION ANGLE* of more than a few degrees, surface features are distorted and accurate measurement becomes very difficult.

5) RESOLUTION CONSTANT: the theoretically determined diameter of the smallest object distinguishable on the high-resolution photographs. The smallest distinguishable object on the low-resolution photograph has a diameter eight times larger than the listed *RESOLUTION CONSTANT*.

6) INCIDENCE ANGLE: the vertical angle between the rays of the sun and the normal to the lunar surface (Figure 3).

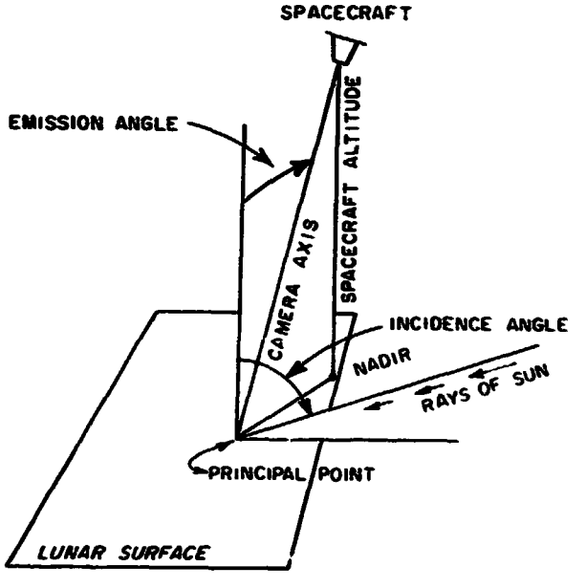

Figure 3: Geometrical definitions of some photogrammetric parameters.

Once the scale has been computed (see above), the *INCIDENCE ANGLE* may be used in conjunction with Figure 4 to determine the height of mountains and walls above adjacent lowlands (see explanation to Figure 4).

SELECTED PHOTOGRAPHS

Introduction

Twenty-six photographs are recommended for use in courses. These are either single photographs or nested sets considered superior for a particular feature or use, or nested sets that illustrate a wide range of features at different scales. The descriptions which follow are intended to provide a general idea of the features illustrated. Exhaustive decriptions are unnecessary and undesirable in the present context.

Most of the photographs are from Lunar Orbiter Mission IV and V, a not surprising result considering that these missions were specifically designed to yield information of geologic value. These provide a wide range in scale, from Orbiter IV low-resolution pictures which show a major portion of the lunar disk at scales of several kilometers per millimeter, to Orbiter V high-resolution pictures with scales on the order of 25 meters to the millimeter.

General Nested Sets

The general nested sets may be used with reasonable success for a number of different purposes. For those with limited time for lunar geology or limited budgets, use of one of these sets is probably the best approach. Both nests include an Orbiter IV low-resolution photograph approximately centered on the area covered by the higher resolution photographs. These low-resolution photographs not only clearly show well-known

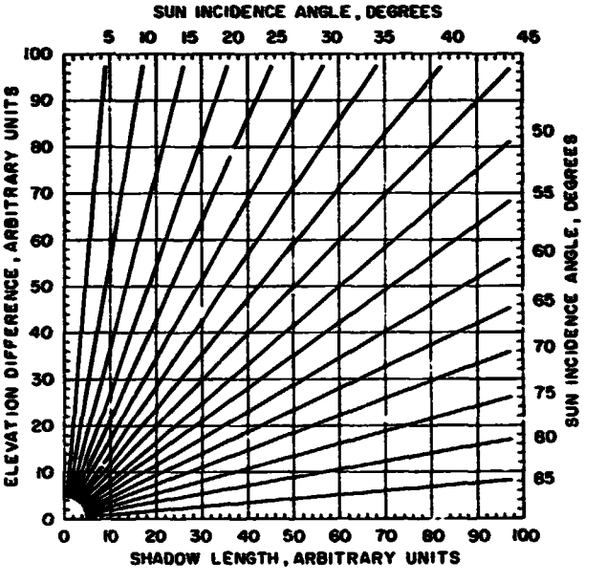
SUN INCIDENCE ANGLE, DEGREES
5 10 15 20 25 30 35 40 45
ELEVATION DIFFERENCE, ARBITRARY UNITS
100 90 80 70 60 50 40 30 20 10 0
SUN INCIDENCE ANGLE, DEGREES
50 55 60 65 70 75 80 85
0 10 20 30 40 50 60 70 80 90 100
SHADOW LENGTH, ARBITRARY UNITS

Figure 4: Diagram for determining relative heights from shadow length. Follow shadow length upward until proper incidence angle value (lines radiating from origin) is intersected, and read corresponding relative height value along left margin in same units used to measure shadow length. Shadow length must be measured directly down sun. It is easier to use the diagram if the decimal point is placed in scales so that determination is as close to the right-hand margin as possible. Decimal point in scales may be moved from one measurement to the next because units are arbitrary. It is, in fact, permissible to multiply shadow length by any factor needed to move reading away from congested lower-left corner of diagram. Elevation difference obtained must, of course, be divided by the same factor.

craters, mountain ranges, maria, etc., but are also sharp enough to permit recognition of the major mappable stratigraphic units. Moreover, they provide a regional framework for the more detailed pictures in the nested set.

1) *Fra Mauro nest*: Photographs IV-114M; IV-120H_3; V-139M; V-139H_1; V-139H_2; V-139H_3. Centered on junction of craters Fra Mauro, Perry, and Bonpland (8° S. Lat., 17° W. Long.). Included on Riphaeus Mountains quadrangle (LAC 76), geology by Eggleton (1965).

Photograph IV-120H_1 is usable for stratigraphic studies, showing pre-Imbrian material on the crater rims, part of the Imbrian ejecta blanket (Fra Mauro Formation), and smooth plains divisible into two or three stratigraphic units. A wide range of crater ages is also present. Some of the dark material is associated with and covers a rille, and may be volcanic. This material is shown in greater detail on V-139M and V-139H_2. Age relationships between graben-like rilles and stratigraphic units are well shown on IV-120H_3 and V-139M. The Orbiter V high-resolution photographs illustrate such surficial details as variation in morphology of small craters (presumably a function of age), patterned ground on slopes, concentrations of large blocks of rock (not a very good example for this feature), and variation in crater density.

2) *Alphonsus nest*: Photographs IV-108M; IV-108H_2; V-117M; V-118H_2; V-118H_3. Centered on western rim of crater Alphonsus (14° S. Lat., 4° W. Long.). Largely included on the Ptolemaeus quadrangle (LAC 77), geology by Howard and Marsursky (1968).

Photograph IV-108H_2 shows pre-Imbrian material in the rims of old craters modified by the Imbrian "sculpture," and younger smooth plains materials divisible into two or three mappable units. A moderately good range of crater ages is present. The three major craters—Ptolemaeus, Alphonsus and Arzachel—show different degrees of rim degradation, suggesting that they are of different ages.

Alphonsus has several dark spots on its floor spatially related to rilles and pits. One of these spots is shown in detail on V-117M and V-118H_2. The latter photography clearly illustrates the difference in crater density between the dark spot and a lighter area of crater floor in the northwestern corner of the photograph. These dark spots are suggestive of volcanic activity, as is a crater chain in the northwestern corner of IV-108H_2.

Photographs V-118H_2 and V-118H_3 also provide an excellent example of patterned ground, and show variation in morphology of small craters. The crater Arzachel illustrates large-scale slumping of crater walls (photograph IV-108H_2). Both Arzachel and Alphonsus have central peaks.

If only one nest is obtained, the one to get will depend on the user's primary objectives. The Fra Mauro set includes the better low-resolution Orbiter IV photograph because it is centered near the southern margin of Mare Imbrium which is used as the type area for lunar mapping by the U.S. Geological Survey. In addition, photograph IV-120H_3 is better for stratigraphic studies than is IV-108H_2. On the other hand, the Alphonsus set includes more convincing examples of volcanic features and deposits, as well as better examples of patterned ground, slumping of crater walls, and the correlation of crater density with relative age.

Photographs for Stratigraphic Studies

On the basis of clarity of superposition and cross-cutting relationships, the number of mappable units, and the total relative age range present, three photographs (IV-109H_3, IV-169H_2, and IV-97H_2) are considered superior single photographs for stratigraphic studies. Mapping units may be distinguished from each other by albedo (relative brightness), crater density, and topographic texture. They may be arranged in stratigraphic sequence by superposition, embaying relationships, crater density, and contrasting relationships with structural features such as craters and rilles. Good general summaries of the lunar stratigraphic scheme are those by Shoemaker (1964), McCauley (1967b), Mutch (1970, p. 117-139), and Wilhelms (in press). The scheme has changed somewhat with time, as best explained by McCauley (1967b) and Wilhelms (in press).

Photograph IV-109H_3, which is probably the best of the three, is in the southeastern part of Mare Imbrium and includes most of the crater Archimedes. The area is included on the Montes Apenninus quadrangle (LAC 41), geology by Hackman (1966). Photograph IV-169H_2 is next best and is along the southwestern edge of Oceanus Procellarum. No published quadrangle includes this area. The third photograph, IV-97H_2, is included on four quadrangles: Mare Vaporum (LAC 59), geology by Wilhelms (1968); Julius Caesar (LAC 60), geology by Morris and Wilhelms (1967); Mare Serenitatis (LAC 42), geology by Carr (1966); and Montes Apenninus (LAC 41), geology by Hackman (1966).

Photograph IV-114M from the Fra Mauro nest may be used to provide a regional frame for both IV-109H_3 and IV-97H_2.

Photographs of Specific Features

1) *Volcanic landforms*: Photographs IV-157H_2, V-214M; and V-216H_3, on Hevelius quadrangle (LAC

56), geology by McCauley (1967a) constitute a nested set showing the Marius Hills in the center of Oceanus Procellarum. This area provides the most convincing evidence of volcanism on the moon (McCauley, 1967a; Mutch, 1970, p. 217-231). The Orbiter IV photograph is covered with domes and steep-sided peaks, many with summit pits, plus sinuous rilles and wrinkle ridges. The higher resolution pictures supply many interesting details, including crater types directly comparable to types associated with terrestrial volcanism. Photograph II-213M is an interesting oblique view of this area, but because this picture has been reproduced by Mutch (1970, p. 218), by Kosofsky and El-Baz (1970, p. 122), and by Lowman (1969, plate 86), it is probably not necessary to buy it.

2) *Impact crater morphology*: Photographs V-197; V-199H_2; and V-201H_3, on Aristarchus quadrangle (LAC 39), geology by Moore (1965). The medium-resolution photograph clearly shows the radial zoning of the raised rim of Aristarchus, slumping of the inner wall of the rim, the radial array of secondary craters, the central peak, and numerous minor characteristics. Shoemaker (1962) presents a discussion of the characteristics and probable origin of craters similar to Aristarchus. Photograph V-199H_2 is a close-up of the northern portion of the inside of the crater showing numerous concentrations of large boulders, the peculiar "blistery" topography of much of the crater floor, and patterns suggestive of the flow of some fluid material down the inner wall of the rim. Photograph V-201H_3 is a close-up of a portion of the outer rim. It includes some of the most convincing flows on the moon—features with lobate forms raised above the surroundings, smoother and darker surfaces than surrounding terrain, and very low crater densities.

3) *Sinuous rille*: V-204M and V-204H_3 on Aristarchus and Seleucus quadrangles (LAC 39 and 38), geology by Moore (1965 and 1967), are a nested pair of photographs of a portion of Vallis Schröteri on the Aristarchus Plateau in Oceanus Procellarum. This sinuous rille has a smaller, meandering rille within it which shows what appears to be a cut-off meander and partial burial of a meander loop by talus from the wall of the larger rille. This meandering inner rille is particularly controversial because it so closely resembles terrestrial stream channels, yet may have a totally different origin (e.g., Schumm, 1970).

Photograph V-204M includes a small segment of the crater Aristarchus in the southeastern corner, and the radial array of secondary impacts from this crater covers nearly half the photograph. Patterned ground and boulder concentrations at the bases of slopes are visible on V-204H_3, with one visible track left by a rolled boulder in framelet 202.

4) *Crater chain*: Photographs V-94M and V-95H_1, on Mare Vaporum quadrangle (LAC 59), geology by Wilhelms (1968). This is a nested pair of the Hyginus Rille, near the center of the visible disk. This feature is large enough to be clearly visible on the low-resolution Orbiter IV photographs listed under the nested sets. Rima Hyginus is the classic example of a rille that is also a crater chain. The craters of the chain have been interpreted as volcanic by Wilhelms (1968). The lunar surface appears darker and possibly slightly less cratered near the rille than elsewhere, perhaps due to a covering of pyroclastic deposits. The high-resolution photograph shows a portion of the largest crater (Hyginus) along the rille, a crater very different in appearance from those generally explained as due to impact. The walls of this crater show patterned ground, boulder concentrations, and some good examples of tracks left by rolled boulders.

5) *Maria vs. terrae*: Photographs III-213M and IV-161H_3, on Grimaldi quadrangle (LAC 74) illustrate the contrasts between maria and terrae in topography, albedo, smoothness, and fracture patterns. Photograph III-213M is an oblique picture of a portion of the western shore of Oceanus Procellarum, whereas IV-161H_3 is a partially overlapping vertical photograph. Although the primary purpose of these photographs is to illustrate the differences between the two major types of terrain on the moon, they also provide excellent views of wrinkle ridges, graben-like rilles, a crater with a floor webbed by branching rilles, and a systematic grid-like alignment of small topographic forms on the terrae. The photographs are also useful for illustrating the distortion created by oblique views.

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APPENDIX: SOURCES OF MATERIAL

Lunar Orbiter Photographs

The photographs and supporting data are obtained from:
Data Services Branch
National Space Science Data Center
Goddard Space Flight Center
Code 601.4
Greenbelt, Maryland 20771

The first step is to request the following guide to ordering
Beeler, M. and Michlovitz, K., 1969, *Lunar Orbiter Photographic Data*: NASA, NSSDC 69-05.

This publication includes complete Orbiter index maps as

well as instructions for ordering photographs. The 20"x24" prints of the Orbiter photographs referred to in the text of this paper are the NASA-LRC enhancements, which cost about $4.00[1] each. The Data Center will provide all Orbiter photographs on microfilm for $27.00[1]. Although the microfilm versions of the photographs were noticeably degraded in quality, they are very convenient as an aid to ordering additional full-sized prints.

When ordering Orbiter photographs, it is important to emphasize that high resolution pictures are being identified according to the NASA-LRC numbering system (1 to 3 from south to north for L.O. IV. 1 to 3 from east to west for L.O. V). Many people order according to the AMS numbering system which is exactly opposite this one. It may be helpful to tell the Data Center which end of the strip (north or south, east or west) you want in addition to giving them the proper NASA-LRC number. The microfilm set we have is numbered according to the AMS system, so care must also be exercised in placing orders for additional pictures.

Apollo Lunar Photographs

The Data Center also provides copies of Apollo pictures, for which various indexes have been published. Available on request as of October, 1970, are:

1) *Apollo 8 Lunar Photography; 70mm Frame Index*: NASA, NSSDC 69-06.
2) *Apollo 10 Photography Index; 70mm and 16mm Frame Index*: NASA, NSSDC 69-14.
3) *Apollo 11 Photography; 70mm, 16mm, and 35mm Frame Index*: NASA, NSSDC 70-72.
4) *Apollo 11 70mm Photographic Catalog*: NASA, NSSDC 70-07.
5) *Apollo 12 Lunar Photography*: NASA, NSSDC 70-09.
6) *Apollo 12 70mm Photographic Catalog*: NASA NSSDC 70-10.
7) *Apollo 12 Photography; 70mm, 16mm, and 35mm Frame Index*: NASA, NSSDC 70-11.

Charts and Maps

Except for number 1, all the following items are obtainable from:

Superintendent of Documents
U.S. Government Printing Office
Washington, D.C. 20402

1) *U. S. Geological Survey geologic quadrangle maps of the moon*: These are sold by the U.S. Geological Survey, Washington, D.C. for $1.00 each.

2) *U.S. Air Force Lunar Reference Mosaic:* An orthographic projection of the lunar near side identifying major features. Available in two sizes:

a) LEM-1, scale 1:5,000,000 lunar diameter =27 inches, price, $1.00.
b) LEM-1B, scale 1:2,500,000, lunar diameter =54 inches, two sheets, price $2.00.

Both sizes are suitable for hanging on the wall for reference and display.

3. *NASA lunar charts*: The entire moon is covered on three sheets at a scale of about 1:5,000,000. The Earthside and Farside charts (covering a belt between 48°N. and 48° S. latitudes) are Mercator projections, the Polar chart is a polar stereographic projection.

a) Lunar Earthside Chart (LMP-1): price, 50¢.
b) Lunar Farside Chart (LMP-2): price, 50¢.
c) Lunar Polar Chart (LMP-3): price, 50¢.

d) *LAC Charts*: These are a series of 1:1,000.000 charts of the near side of the moon, by quadrangles. Quadrangles are identified both by number and by the name of a prominent feature included. Each chart includes an index to the locations of all charts, price, 50¢ each.

5) *Other charts and publications relating to the moon*: Request from the Superintendent of Documents, the price list for publications dealing with "space."

[1]These prices should be checked with the Data Center before ordering.

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